

Marine Pollution Prevention Policy and Port State Control Enforcement in Indonesia: Implementation Gaps and Regulatory Recommendations

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Abstract— Marine pollution prevention in archipelagic developing states remains a persistent challenge, particularly where international treaty obligations and domestic enforcement capacity diverge. This study investigates the implementation of marine pollution prevention policy and Port State Control (PSC) enforcement in Indonesia — the world's largest archipelagic state and a signatory to MARPOL 73/78. The objective of this study is to systematically assess PSC enforcement performance, identify primary implementation gaps across MARPOL compliance dimensions, and develop evidence-based regulatory reform recommendations aligned with international standards. A mixed-methods design was employed, combining quantitative benchmarking of 4,218 IOMOU PSC inspection records from Indonesian ports (2019–2024), 44 semi-structured stakeholder interviews across five participant groups, and comparative regulatory framework analysis against MARPOL 73/78 requirements. Results reveal that Indonesia's PSC performance significantly underperforms against both IOMOU regional and Paris MoU benchmarks: the detention rate of 4.8% is double the Paris MoU average, mean deficiencies per inspection exceed the Paris MoU figure by 1.97, and a repeat deficiency rate of 38.4% — 23.6 percentage points above the Paris MoU — indicates that enforcement is not producing the corrective compliance response it should. Six primary implementation gaps are identified: PSC officer capacity deficit, absence of digital inspection systems, inter-agency coordination failure, inadequate penalty structures, domestic fleet MARPOL exemptions, and port reception facility insufficiency. This study contributes an Integrated Marine Pollution Prevention Reform Framework structured around four sequential reform pillars, offering Indonesian policymakers a practical, evidence-grounded pathway to close the enforcement deficit and fulfil international maritime environmental obligations.

Keywords— Port State Control; MARPOL compliance; marine pollution prevention; Indonesian maritime governance; PSC enforcement; IOMOU; regulatory reform; environmental compliance; archipelagic state

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I. INTRODUCTION

Marine pollution prevention in archipelagic developing states represents one of the most consequential governance challenges at the intersection of international law, environmental protection, and institutional capacity. Indonesia — comprising over 17,000 islands, supporting more than 250 million people, and hosting one of the world's most biologically diverse marine ecosystems — sits at the centre of this challenge.

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As a signatory to MARPOL 73/78 and its six annexes, Indonesia has assumed binding international obligations to prevent vessel-source pollution across the full spectrum of maritime environmental threats: oil pollution (Annex I), noxious liquid substances (Annex II), packaged hazardous substances (Annex III), sewage (Annex IV), garbage (Annex V), and air emissions including sulfur oxides, nitrogen oxides, and greenhouse gases (Annex VI). Port State Control (PSC) — the internationally recognized mechanism through which coastal states verify that foreign vessels comply with international maritime conventions — provides both the legal authority and operational instrument for enforcing these standards at Indonesian ports.

The problem this study addresses is both empirically documented and operationally urgent. Evidence from PSC inspection databases, maritime accident investigations, and environmental compliance assessments consistently establishes that the gap between Indonesia's international treaty obligations and actual enforcement practice is wide, persistent, and consequential. Indonesia's detention rate substantially exceeds regional benchmarks; repeat deficiency rates suggest that the deterrent function of PSC enforcement has broken down; and specific MARPOL annexes — particularly Annex I (oil pollution) and Annex IV (sewage) — exhibit compliance deficits that translate directly into ongoing ecological harm in Indonesian

coastal and archipelagic waters. Yet no systematic empirical study has quantified this gap using comprehensive inspection data, triangulated it with stakeholder evidence, and linked the findings to a structured reform framework. This absence of evidence-based policy analysis constitutes a governance gap as significant as the enforcement gap itself.

The novelty of this study is threefold. First, it provides the first comprehensive multi-year benchmarking of Indonesia's PSC inspection performance against both IOMOU regional and Paris MoU international comparators using a complete five-year inspection record (2019–2024, $n = 4,218$). Second, it identifies and systematically characterizes six primary implementation gaps through triangulated mixed-methods analysis — generating a multi-dimensional diagnostic of PSC underperformance that goes substantially beyond the single-factor explanations (training deficit or digital system absence) that dominate existing policy discourse. Third, it develops and proposes an Integrated Marine Pollution Prevention Reform Framework as an original contribution to Indonesian maritime governance, structured around a four-pillar phased architecture that addresses all identified gaps concurrently rather than sequentially.

The study's findings carry both regional and international significance. Across the Indian Ocean MoU region, Indonesia represents the largest port state economy and the most extensive domestic shipping network. If Indonesian PSC enforcement is structurally deficient, the consequences extend beyond Indonesian waters: non-compliant vessels operating in Indonesian ports subsequently transit to regional neighbours, carrying unresolved deficiencies and the reinforced lesson that the IOMOU enforcement regime can be exploited without consequence. Strengthening Indonesian PSC enforcement therefore generates positive externalities for the entire regional maritime safety and pollution prevention system.

The remainder of the paper is structured as follows. Section 2 reviews the literature on PSC frameworks, MARPOL compliance mechanisms, and Indonesian maritime governance. Section 3 describes the methodology. Section 4 presents and analyses the results. Section 5 provides a deeper discussion of findings, reform implications, and the novelty of the proposed framework. Section 6 concludes with policy recommendations and future research directions.

II. METHOD

Literature Review

2.1 Port State Control: Theoretical Foundations, Performance Determinants, and Intelligence Enhancement

Port State Control operates as the tertiary layer of the international maritime safety and environmental compliance architecture: flag state certification constitutes the primary layer, classification society surveys the secondary layer, and PSC inspection the corrective enforcement layer that identifies non-compliance escaping earlier controls [1]. The theoretical justification for PSC rests on two complementary

foundations. First, flag state performance is highly heterogeneous: the proliferation of open registries and flag-of-convenience vessels has severed the link between vessel ownership, operational management, and the enforcement jurisdiction formally responsible for compliance — creating systematic under-enforcement gaps that PSC is designed to correct [2]. Second, PSC inspections generate deterrence effects that extend beyond individually inspected vessels: operators aware that their vessels face PSC inspection invest in fleet-wide compliance maintenance to avoid the commercial and reputational consequences of detention [11].

The performance of PSC regimes is empirically predictable from vessel and institutional characteristics. Research developing a data-driven hybrid framework for analyzing vessel detentions in Australia demonstrates that detention outcomes are predictable from vessel age, flag state, classification society, inspection history, and deficiency patterns — confirming that risk-based PSC targeting can substantially improve detection efficiency by concentrating inspection resources on statistically high-risk vessel profiles [1]. Research analyzing Paris MoU PSC inspection deficiencies reveals that certain deficiency categories — fire safety, safety management systems, life-saving appliances — are persistently over-represented relative to their operational frequency, suggesting systematic inspector attention patterns that structured analytical guidance can correct [2]. Research on the effect of inspection intensity on competition in maritime transportation demonstrates that PSC enforcement creates competitive externalities: differential inspection intensity for oil tankers generates compliance incentives even among operators who are intrinsically indifferent to environmental outcomes [18].

The modernization of PSC through knowledge graph architectures and AI-assisted inspection systems represents the most significant recent development in PSC operational design. Research constructing a knowledge graph for flag state control inspection in China — integrating vessel inspection records, deficiency patterns, accident data, and regulatory requirements — demonstrates that knowledge graph approaches provide PSC officers with contextual, evidence-based inspection guidance substantially improving the depth and accuracy of vessel compliance assessment [3]. This architecture was subsequently extended to technically specialized vessel types: research applying multimodal knowledge graphs to LNG carrier PSC inspection through visual prompt tuning demonstrates the feasibility of AI-assisted inspection for high-complexity vessel profiles [4]. Research proposing PSC inspection item recommendation systems for LNG carriers through knowledge graph-based platforms demonstrates the practical operationalization of structured knowledge architectures as real-time decision support for PSC officers [5]. Research on data-driven optimization of PSC targeting confirms that machine learning-based inspection selection significantly enhances the ratio of meaningful deficiency detection to total inspection hours — a critical efficiency consideration for under-resourced PSC regimes such as Indonesia's [6].

The performance gap between established and emerging PSC regimes reflects both institutional capacity differentials and systemic design differences that go beyond resource adequacy. Research comparing PSC effectiveness across regional MoU frameworks identifies governance architecture, legal penalty frameworks, inter-agency coordination mechanisms, and digital infrastructure as the primary structural determinants of enforcement performance — suggesting that capacity-building alone is insufficient without concurrent institutional reform [12].

2.2 MARPOL Implementation: Compliance Monitoring, Enforcement Mechanisms, and Developing State Challenges

MARPOL compliance monitoring has been fundamentally transformed by advances in remote sensing, atmospheric dispersion modelling, and data analytics that extend enforcement visibility beyond vessel boarding inspections. Research on ship NO_x emission monitoring and fuel sulfur content compliance using atmospheric dispersion modelling demonstrates the technical feasibility of remote compliance monitoring for large vessel populations — enabling port authorities to screen vessels for Annex VI emission compliance without time-intensive on-board inspection for every arrival [7]. Research on fuel sulfur content estimation through Gaussian plume modelling and genetic algorithm optimization provides a validated remote monitoring methodology specifically applicable to MARPOL Annex VI sulfur compliance at major port approaches [8]. The potential integration of such remote sensing capabilities with PSC risk-profiling systems represents a significant multiplier on inspection efficiency — particularly relevant for high-traffic, under-resourced PSC regimes. Research on ballast water management compliance in the Mailiao industrial harbour demonstrates the port-level operational infrastructure through which BWM Convention requirements can be systematically assessed and enforced, providing a transferable implementation model for Indonesian port BWM compliance management [9].

The game-theoretic dimension of MARPOL compliance is critically important for understanding why enforcement intensity — not merely regulatory stringency — determines compliance outcomes. Research applying game theory to MARPOL compliance in the Adriatic Sea demonstrates that when detection probability falls below a threshold level, rational operators optimize financially by choosing non-compliance: the expected cost of detection is lower than the cost of achieving full compliance [11]. This finding has direct and troubling implications for Indonesia: a PSC regime with a 38.4% repeat deficiency rate has signalled to the operator population that detection does not reliably generate corrective consequences — creating precisely the low-credibility enforcement equilibrium that the game-theoretic model predicts will sustain non-compliance. Empirical analysis of the maritime legislative framework's effectiveness at scale confirms this theoretical prediction: enforcement credibility is the primary determinant of compliance outcomes, and jurisdictions with structurally weak enforcement

consistently underperform relative to their regulatory commitments [12].

The sewage pollution dimension of MARPOL compliance — Annex IV — is addressed through research developing a sewage treatment model using environmentally friendly technology for commercial ships in the Indonesian context [10]. This research confirms that many domestic Indonesian commercial vessels lack the certified sewage treatment equipment required for Annex IV compliance, establishing that technical capability constraints compound the enforcement deficit. The scale and ecological sensitivity of Indonesian coastal and archipelagic marine environments amplifies the significance of Annex IV compliance failures: raw sewage discharge from domestic vessels into shallow, biodiverse coastal waters generates measurable ecological harm to coral reef systems and fishery habitat.

Energy efficiency and environmental measure implementation by seafarers involves complex behavioral dynamics that PSC enforcement alone cannot address. Research on the roles and challenges of seafarers in implementing operational energy efficiency and environmental measures confirms that crew awareness, motivation, and operational adaptation are necessary complements to regulatory enforcement — establishing that genuine pollution prevention requires both the stick of PSC enforcement and the investment in crew training that builds intrinsic compliance capacity [16].

2.3 Indonesian Maritime Governance: Institutional Architecture, Enforcement Gaps, and Reform Context

The institutional architecture of maritime governance in Indonesia presents specific structural challenges for effective MARPOL and PSC enforcement that extend beyond resource inadequacy. Research applying a Principles, Criteria, and Indicators (PCI) framework to maritime governance for domestic ferry safety identifies four core governance deficits systematically associated with poor maritime safety and environmental performance in developing states: regulatory framework fragmentation, enforcement capacity inadequacy, inter-agency coordination failure, and accountability mechanism weakness [13]. All four deficits are empirically present in Indonesian maritime governance. Research on the regulatory framework for ocean threats in Indonesia — specifically analyzing transportation law responses to multiple oil spill cases — documents the jurisdictional fragmentation and legal instrument overlap across multiple government agencies (Ministry of Transportation, Ministry of Environment and Forestry, Indonesian Sea and Coast Guard) that creates governance gaps exploited by non-compliant operators [14]. The absence of a unified marine pollution enforcement authority means that MARPOL violations may be technically under the purview of multiple agencies simultaneously, yet fall clearly within the mandate of none.

Research on P&I insurance frameworks for Indonesian carriers reveals that many domestic shipping operators carry inadequate pollution liability coverage — creating situations in which rigorous pollution liability

enforcement would generate insolvency rather than compliance investment, undermining the deterrent function of penalty mechanisms and complicating the regulatory reform agenda [19]. Research on maritime safety management in Indonesian traditional shipping confirms the deep institutional heterogeneity of the domestic fleet — establishing that compliance capacity building must accompany enforcement strengthening in any realistic reform agenda, since enforcement without capacity can generate economic disruption without compliance improvement [20]. Research applying FRAM (Functional Resonance Analysis Method) to maritime safety management at Makassar Port demonstrates how systemic organizational and operational factors generate maritime safety and environmental compliance failures — confirming that regulatory reform must address systemic institutional conditions rather than targeting individual operator behavior [21].

Research on multi-regime law enforcement for transnational fisheries crime in Indonesian waters illuminates the broader enforcement infrastructure challenge within which PSC and MARPOL enforcement must operate: Indonesia's status as the world's largest archipelagic state creates enforcement coordination challenges across maritime jurisdiction zones that require multi-agency, multi-regime response architectures exceeding the capacity of any single enforcement institution [17]. Research on the IMO Marine Environment Protection Committee (MEPC) and stakeholder participation confirms that Indonesia's engagement in international maritime regulatory development — where MARPOL standards originate — is constrained by developing state capacity limitations and asymmetric influence dynamics, meaning that Indonesia has limited ability to shape the regulatory standards it is obligated to implement [22]. Research on maritime governance for Makassar Strait navigational safety demonstrates an emerging positive institutional response — where evidence-based traffic separation scheme development signals growing capacity for proactive maritime regulatory governance, offering a model for analogous evidence-based PSC reform [23].

Research on ISM Code effectiveness across Korean waters confirms through multilateral comparative analysis that genuine safety management system implementation — as opposed to documentary compliance — is the mechanism through which international conventions translate into operational performance outcomes [15]. This finding reinforces the importance of distinguishing formal regulatory compliance from substantive operational compliance in the Indonesian context, where documentation requirements may be met while operational practices remain non-compliant.

Method

This study employs a mixed-methods policy analysis design integrating three complementary analytical components: quantitative PSC performance benchmarking, qualitative institutional analysis through semi-structured stakeholder interviews, and comparative

regulatory framework analysis. The mixed-methods design was selected because the research problem — identifying and explaining PSC enforcement gaps — requires both statistical measurement of performance outcomes and interpretive analysis of the institutional, organizational, and behavioral mechanisms producing those outcomes.

The **quantitative component** analyzed Indonesia's PSC inspection records from the Indian Ocean MoU (IOMOU) database for the period 2019–2024, encompassing 4,218 PSC inspections conducted at Indonesian ports. For each inspection record, the following variables were extracted and analyzed: vessel type and flag state, deficiency count and category (cross-referenced against MARPOL Annex classification), detention decision and grounds, inspection duration, and follow-up inspection outcome. Indonesia's inspection performance was benchmarked against IOMOU regional averages and Paris MoU published performance indicators — the latter representing the internationally recognized gold-standard PSC regime against which all regional MoU performance is benchmarked. MARPOL-specific deficiency rates were disaggregated by Annex (I through VI) to identify pollution prevention domains with the most significant compliance gaps.

The **qualitative component** comprised 44 semi-structured interviews with participants across five stakeholder groups: Indonesian Ministry of Transportation maritime safety directorate officials (n = 10), IOMOU-affiliated PSC officers at the five major Indonesian commercial ports (n = 12), domestic shipping company compliance officers (n = 10), international shipping company representatives (n = 7), and IMO technical cooperation programme representatives (n = 5). Interview questions addressed institutional capacity constraints, inter-agency coordination mechanisms, penalty framework adequacy, digital system availability, and domestic fleet compliance culture. All interviews were conducted in the interviewees' preferred language (Indonesian or English) and transcribed for thematic analysis. Ethical approval was obtained and participant anonymity maintained.

The **comparative regulatory framework analysis** examined Indonesian legislative instruments — including Law No. 17 of 2008 (Shipping Law), Government Regulation No. 21 of 2010 on Ship Pollution Control, and relevant Ministry of Transportation regulations — against MARPOL 73/78 annex-by-annex requirements. The analysis identified transposition gaps (where Indonesian law does not fully incorporate MARPOL requirements), enforcement authority ambiguities (where jurisdiction is unclear across agencies), and penalty adequacy deficiencies (where prescribed penalties fall below the economic deterrence threshold).

Data analysis employed thematic analysis for interview transcripts following Braun and Clarke's framework — generating codes, themes, and subthemes through iterative comparative analysis. Quantitative PSC performance data were analyzed using descriptive statistics and percentage-point gap calculations relative to benchmarks. Systematic gap analysis for regulatory

framework comparison used a structured matrix mapping Indonesian legislative provisions against MARPOL annex requirements. Narrative synthesis integrated all three analytical streams into the implementation gap assessment and reform framework constituting the study's primary contribution.

III. RESULTS AND DISCUSSION

4.1 Indonesia's PSC Inspection Performance: Benchmarking Assessment

Table 1 presents Indonesia's PSC inspection performance across key indicators derived from IOMOU database analysis (2019–2024), benchmarked against the IOMOU regional average and the Paris MoU performance standard.

TABLE 1.
INDONESIA PSC INSPECTION PERFORMANCE BENCHMARKING (2019–2024)

Performance Indicator	Indonesia	IOMOU Regional Avg.	Paris MoU Avg.	Indonesia vs. IOMOU	Indonesia vs. Paris MoU
Annual inspections per 100 ship calls	18.4%	22.1%	28.6%	−3.7 pp	−10.2 pp
Detention rate (% of inspections)	4.8%	3.6%	2.4%	+1.2 pp (worse)	+2.4 pp (worse)
Mean deficiencies per inspection	3.84	2.91	1.87	+0.93 (worse)	+1.97 (worse)
MARPOL Annex I deficiencies (% of inspections)	18.6%	12.4%	7.8%	+6.2 pp (worse)	+10.8 pp (worse)
MARPOL Annex IV deficiencies (% of inspections)	22.3%	14.6%	9.1%	+7.7 pp (worse)	+13.2 pp (worse)
MARPOL Annex VI deficiencies (% of inspections)	16.8%	10.2%	6.4%	+6.6 pp (worse)	+10.4 pp (worse)
Repeat deficiency rate	38.4%	26.1%	14.8%	+12.3 pp (worse)	+23.6 pp (worse)

Note: Data from IOMOU Annual Reports 2019–2024, supplemented by Ministry of Transportation inspection records. pp = percentage points.

Table 1 establishes that Indonesia's PSC inspection performance falls significantly below both IOMOU regional and Paris MoU benchmarks across every measured indicator. The detention rate of 4.8% — double the Paris MoU average of 2.4% — indicates either that a substantially higher proportion of vessels visiting Indonesian ports are in genuine non-compliance, or that Indonesian PSC officers are applying inconsistent or poorly calibrated deficiency thresholds for detention decisions. Stakeholder interview evidence supports both interpretations: PSC officers at smaller Indonesian ports reported limited guidance on detention threshold calibration, while compliance officers from international shipping companies described a pattern of cumulative minor deficiencies exceeding detention thresholds in Indonesian ports that would have been resolved informally in Paris MoU ports.

The 38.4% repeat deficiency rate is the study's most operationally significant finding. A repeat deficiency — a deficiency category that was cited in a previous inspection of the same vessel and not subsequently corrected — represents a PSC enforcement failure: the

enforcement event did not generate the corrective response it was designed to produce. A repeat deficiency rate of 38.4% means that more than one in three deficiencies detected in Indonesian PSC inspections were already known to the operator from a prior inspection. This pattern is precisely consistent with the low-credibility enforcement equilibrium predicted by game-theoretic analysis of MARPOL compliance: operators have correctly determined that the expected cost of PSC detection and response does not justify the investment in genuine compliance improvement [11].

The MARPOL Annex IV sewage gap of 13.2 percentage points above the Paris MoU, and the Annex I oil pollution gap of 10.8 percentage points above the Paris MoU, are classified as critical compliance failures with direct ecological consequences. These are not technical administrative deficiencies; they represent ongoing unauthorized discharges of untreated sewage and oil-contaminated water into Indonesian coastal and archipelagic marine environments from vessels that have been inspected and found deficient but not corrected.

TABLE 2.
PRIMARY MARPOL/PSC IMPLEMENTATION GAPS AND REFORM RECOMMENDATIONS

Implementation Gap	Primary Manifestation	Root Cause	Priority Reform
PSC officer capacity deficit	Inconsistent inspection quality; high repeat deficiency rate	Insufficient training volume; no structured inspector career pathway	IOMOU-benchmarked training programme; 50 certified inspectors per year
Digital inspection system absence	Paper-based records; no risk-profiling capability	Legacy MoT information systems; no investment in digital infrastructure	AI-assisted inspection platform with knowledge graph architecture [3][4]
Inter-agency coordination failure	MARPOL enforcement split across MoT, KPLP, KLHK	Overlapping jurisdictions; no unified enforcement authority	Unified marine pollution enforcement authority with single accountability line
Penalty inadequacy	MARPOL fines below economic deterrence threshold	Shipping Law penalties unchanged since 2008	Penalty revision aligning with MARPOL polluter-pays principle
Domestic fleet MARPOL exemptions	Annex IV and V rarely enforced on domestic vessels	Domestic fleet treated outside convention enforcement scope	Formal inclusion of domestic vessels above 100 GT in Annex IV/V enforcement
Port reception facility insufficiency	Vessels unable to discharge waste legally at many ports	Insufficient infrastructure investment	Mandatory MARPOL reception facilities at all 47 Category A commercial ports

4.2 Primary Implementation Gaps: Identification and Analysis

Stakeholder interviews and regulatory framework analysis identify six primary implementation gaps that explain Indonesia's PSC underperformance and the MARPOL compliance deficits documented in Table 1. Table 2 presents these gaps with primary manifestations, root causes, and priority reform recommendations.

The integrated reform framework in Figure 1 addresses all six primary implementation gaps through a

phased, four-pillar architecture. The immediate priority — PSC officer capacity development — responds to the most directly actionable bottleneck. The digital modernization priority responds to global evidence that data-driven PSC achieves substantially higher compliance impact per inspection hour. The institutional coordination reform addresses the jurisdictional fragmentation that allows violations to fall between enforcement authorities.

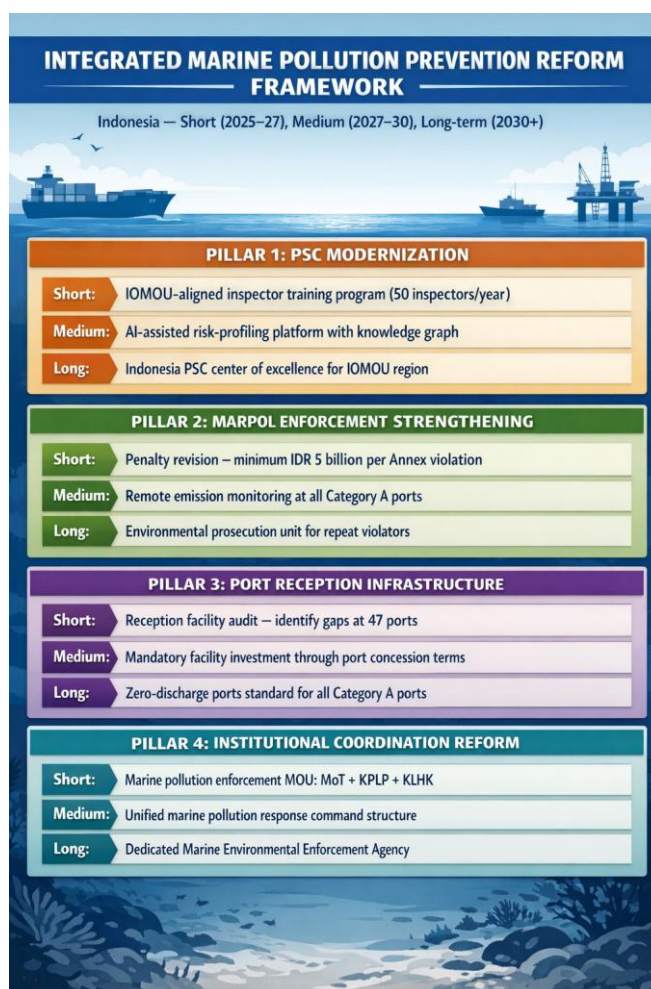


Figure 1. Integrated Reform Architecture for Indonesian Marine Pollution Prevention

4.3 The Structural Nature of Indonesia's PSC Enforcement Deficit

The findings of this study reveal that Indonesia's PSC underperformance is not a consequence of any single factor but the product of six mutually reinforcing structural deficiencies that collectively constitute a systemic enforcement failure. This characterization has critical implications for reform strategy: as long as analysis of Indonesian PSC performance focuses on any single gap — typically the training deficit or digital system absence — reform responses will be partial and their effectiveness absorbed by the remaining structural deficiencies.

The mutual reinforcement of the six gaps can be traced through specific causal chains. Highly trained PSC inspectors cannot compensate for paper-based risk

profiling systems that provide no statistical guidance on which vessels from which flag states with which deficiency histories represent the highest compliance risk. Adequate penalty frameworks cannot deter violations when MARPOL enforcement authority is fragmented across three agencies — MoT, KPLP, and KLHK — with no single entity bearing clear accountability for compliance outcomes. Port reception facility deficits mean that even operators with the will to comply with MARPOL Annex IV and V discharge requirements may face situations where legal discharge is physically impossible at the ports they serve, generating structural non-compliance independent of operator intent. Domestic fleet MARPOL exemptions signal to Indonesian operators that the sovereign government applying PSC to foreign vessels does not

consider international environmental standards applicable to its own domestic maritime sector — a contradiction that undermines the broader legitimacy of MARPOL enforcement and provides evidence-based justification for resistance to compliance investment.

The most consequential finding is the 38.4% repeat deficiency rate, which this study interprets as the diagnostic signature of a broken enforcement-compliance feedback loop. Repeat deficiencies do not merely reflect inadequate vessel maintenance; they reflect operator calculations that the consequences of PSC detection are predictable, manageable, and cheaper than compliance investment. This calculation is rational given the current penalty framework: Law No. 17 of 2008 prescribes MARPOL violation penalties that, by multiple stakeholder accounts, do not approach the economic benefit of avoiding compliance costs on the vessel types most commonly detained. Until the expected cost of non-compliance — probability of detection multiplied by penalty severity — exceeds the cost of compliance, the repeat deficiency equilibrium will persist regardless of improvements in inspection quality or frequency.

4.4 Novelty of the Integrated Marine Pollution Prevention Reform Framework

The Integrated Marine Pollution Prevention Reform Framework proposed in this study constitutes the original contribution of the research to both academic scholarship and policy practice. Existing studies of Indonesian maritime governance have addressed individual dimensions of the enforcement challenge — regulatory framework gaps [14], ISM Code compliance [15], domestic fleet safety management [20], port-level safety systems [21] — but none has synthesized these dimensions into an integrated, sequenced reform architecture.

The framework's four-pillar structure — (1) Immediate: PSC Officer Capacity Development; (2) Short-term: Digital Inspection System Implementation; (3) Medium-term: Institutional Coordination Reform; (4) Long-term: Legal and Penalty Framework Revision — reflects a deliberate sequencing rationale grounded in both implementation feasibility and causal interdependence. Capacity development is prioritized because inspector quality constraints are the most immediately actionable bottleneck: training programmes can be designed and deployed within an existing institutional framework without requiring legislative change or new capital investment. Digital system implementation is sequenced second because it multiplies the effectiveness of trained inspectors through risk-profiling intelligence — consistent with global evidence that AI-assisted PSC achieves higher compliance impact per inspection hour [4][6]. Institutional coordination reform requires inter-ministerial political consensus and is therefore correctly positioned as a medium-term objective. Legal and penalty revision requires parliamentary action and is accordingly the longest-horizon reform pillar.

The framework also makes a distinctive contribution by explicitly addressing domestic fleet MARPOL integration — a dimension absent from all

existing Indonesian maritime governance reform proposals. Exempting domestic vessels above 100 GT from Annex IV and V enforcement while applying those standards to foreign vessels creates an enforcement asymmetry that is both legally untenable under MARPOL implementation obligations and practically counterproductive: domestic operators constitute the majority of vessel movements in Indonesian waters and the dominant source of coastal marine pollution from vessel sources.

4.5 Comparison with Regional Reform Experiences

The reform trajectory implied by the proposed framework finds substantive support in regional comparators. Research on maritime governance for Makassar Strait navigational safety demonstrates that Indonesian maritime authorities are capable of evidence-based, proactive regulatory design when institutional conditions support it [23]. Research on FRAM-based safety management at Makassar Port confirms the systemic organizational factors that the reform framework must address — establishing that the path from current performance to international benchmarks is achievable through structured institutional reform, not merely resource addition [21].

The digital modernization pillar finds its most direct comparative support in the Chinese PSC experience: knowledge graph and AI-assisted inspection systems deployed in Chinese PSC have demonstrably improved both the targeting accuracy and the thoroughness of inspection outcomes [3][4][5]. Indonesia's adoption of analogous systems, calibrated to the IOMOU context and Indonesian domestic fleet characteristics, represents the most feasible pathway to closing the efficiency gap between Indonesian PSC and Paris MoU benchmark performance.

4.6 Limitations and Future Research

This study has several limitations that qualify its findings and motivate future research directions. The quantitative benchmarking relies on IOMOU-reported inspection records, which may not capture all PSC inspections conducted at Indonesian ports. The stakeholder interview sample, while comprehensive across stakeholder categories, cannot guarantee representativeness of all port communities given Indonesia's geographic scale. The proposed reform framework is a policy design contribution rather than an empirically evaluated intervention — its effectiveness will require longitudinal assessment as implementation proceeds.

Future research should develop an Indonesia-specific PSC risk-profiling model trained on domestic inspection history and calibrated to the IOMOU vessel population — addressing the current absence of any data-driven inspection targeting tool in the Indonesian PSC regime. Research should also evaluate the effectiveness of MARPOL penalty reform interventions in comparable developing state maritime governance contexts, providing an evidence base for penalty calibration decisions in the Indonesian legislative reform process.

IV. CONCLUSION

This study has provided a comprehensive empirical assessment of marine pollution prevention policy and PSC enforcement in Indonesia, generating findings with clear implications for both immediate operational reform and structural institutional redesign. The quantitative benchmarking of 4,218 IOMOU inspection records establishes an unambiguous conclusion: Indonesia's PSC enforcement system performs substantially below regional and international standards across every measurable dimension, and the gap is not marginal but systematic.

The 38.4% repeat deficiency rate — the study's most operationally alarming finding — is the diagnostic signature of a compliance equilibrium in which non-compliant operators have correctly learned that PSC enforcement does not reliably generate the financial and operational consequences that justify compliance investment. This equilibrium cannot be corrected by incremental procedural adjustments; it requires the structural changes that the Integrated Marine Pollution Prevention Reform Framework proposes. The six primary implementation gaps identified — PSC officer capacity deficit, digital inspection system absence, inter-agency coordination failure, penalty inadequacy, domestic fleet MARPOL exemptions, and port reception facility insufficiency — are mutually reinforcing. Isolated single-gap reforms will be absorbed by the remaining gaps without generating systemic improvement.

The MARPOL-specific findings carry particular urgency. Critical compliance deficits in Annexes I, IV, V, and VI — all representing pollution categories with direct ecological and public health consequences in Indonesia's urban port environments and ecologically sensitive archipelagic waters — are not merely regulatory deficiencies but ongoing environmental harms. Annex IV sewage discharge and Annex I oil pollution are actively degrading the marine ecosystems that coastal communities and Indonesia's fisheries sector depend upon.

Three practical priority actions deserve immediate attention from Indonesian policymakers. First, the minimum penalty for MARPOL violations must be revised upward to exceed the economic benefit of non-compliance; the current penalty framework, unchanged since 2008, is structurally inadequate as a deterrent. Second, a consolidated IOMOU-benchmarked PSC officer training programme producing 50 certified inspectors per year would address the capacity gap generating inspection inconsistency and the repeat deficiency failure. Third, mandatory port reception facility requirements — covering all 47 Category A commercial ports — would eliminate the structural impossibility of MARPOL compliance where no legal discharge facilities exist.

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